Characterization of the Hamamatsu R11780 12-inch Photomultiplier tube

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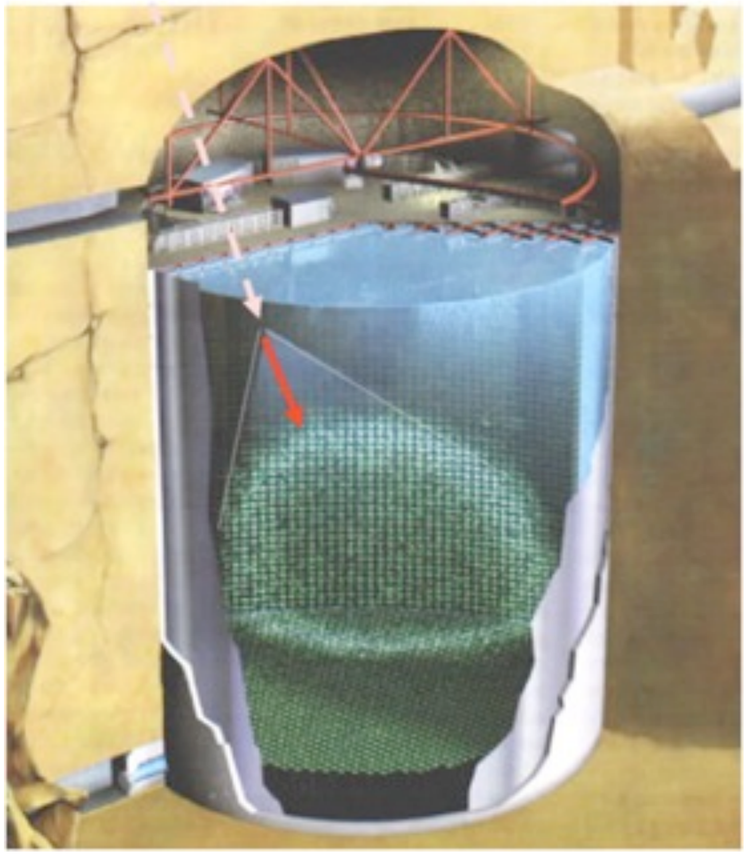
Project-X Physics Study Workshop

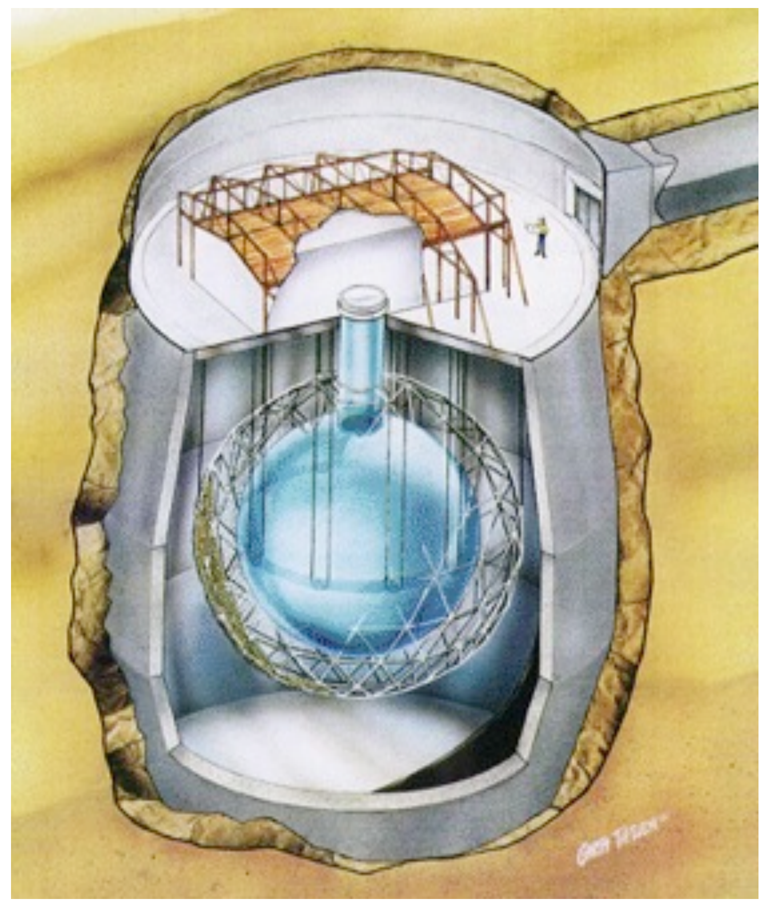
Penn

Neutrino Mixing Angles Measured with Optical Detectors



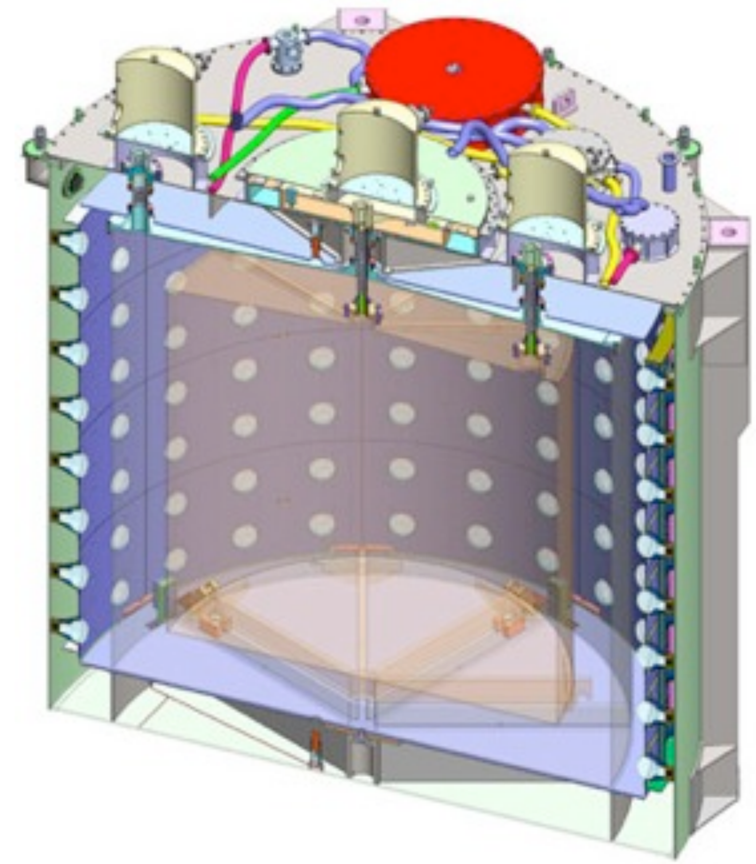
Super-K

θ_{23}



SNO

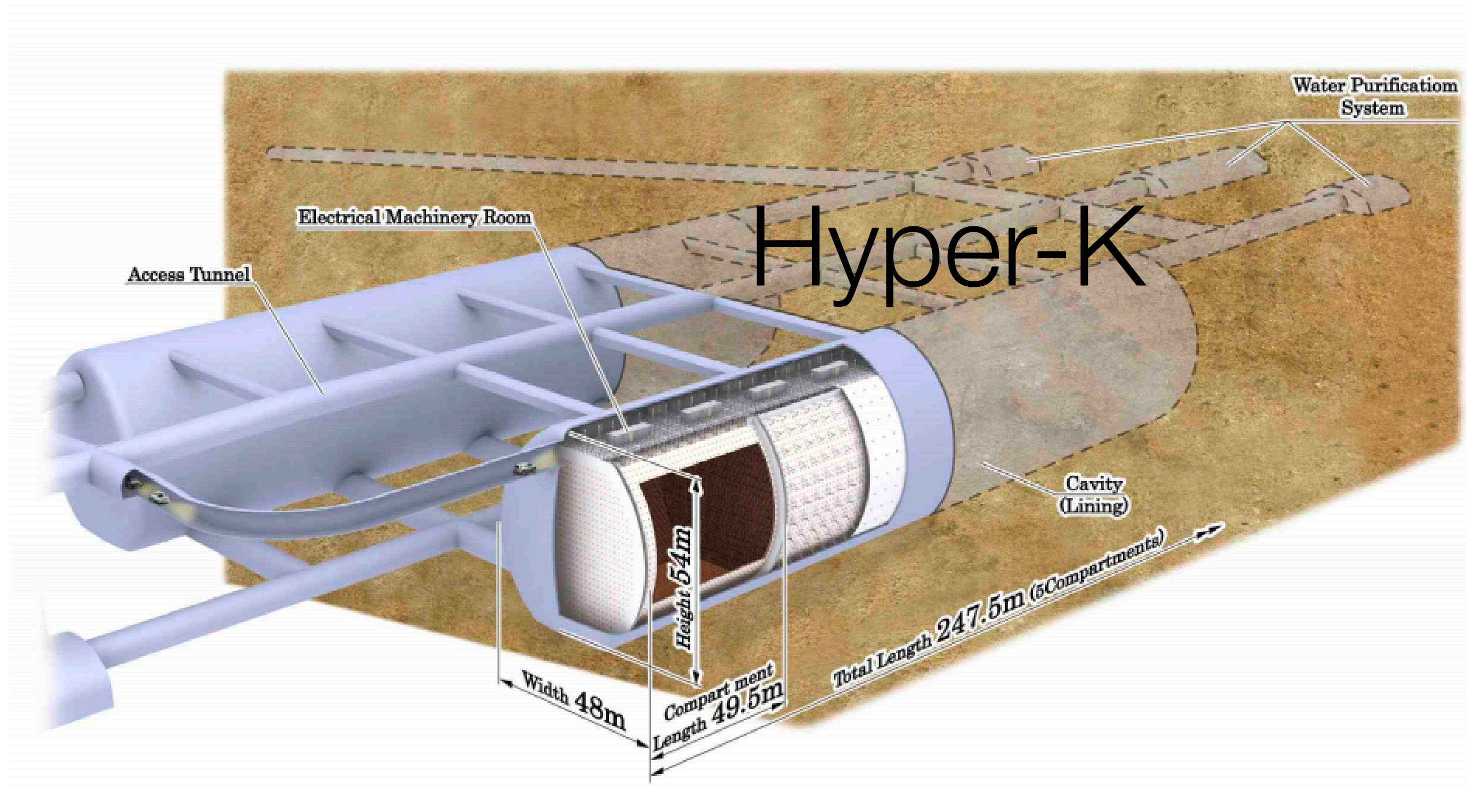
θ_{12}

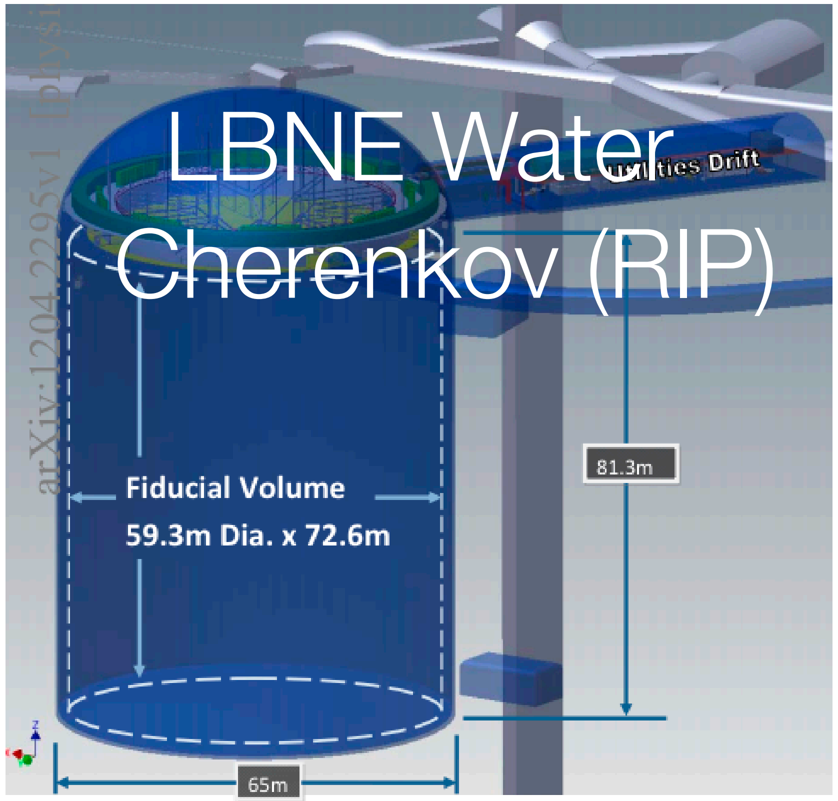


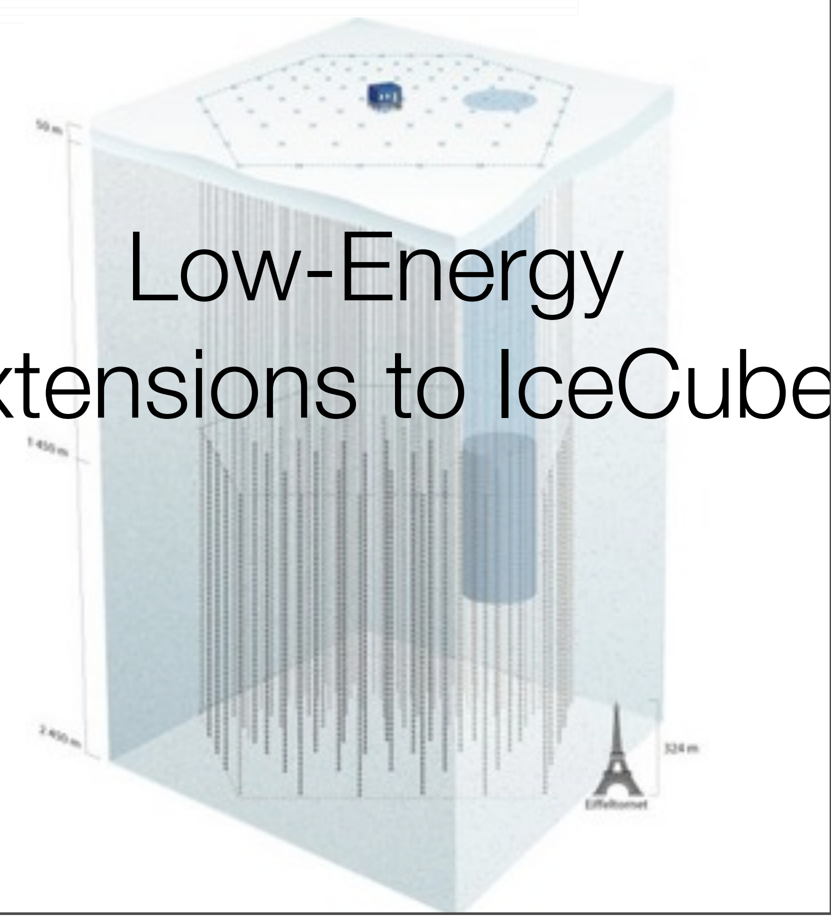
Daya Bay

θ_{13}

Many Future Neutrino Experiments Are Large Optical Detectors and Require PMT R&D







Important PMT characteristics

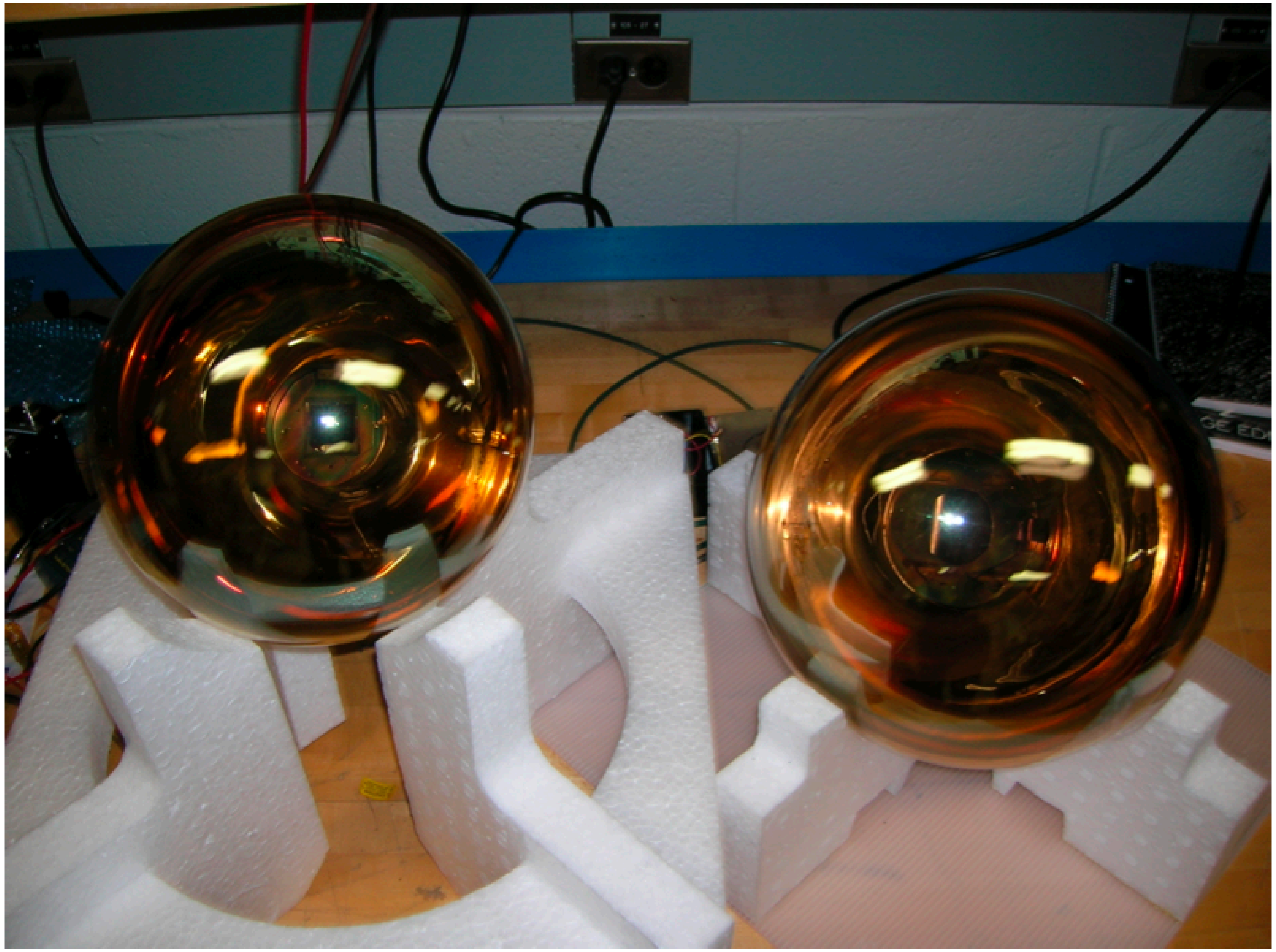
Important for Position Reconstruction

Important for Energy Reconstruction

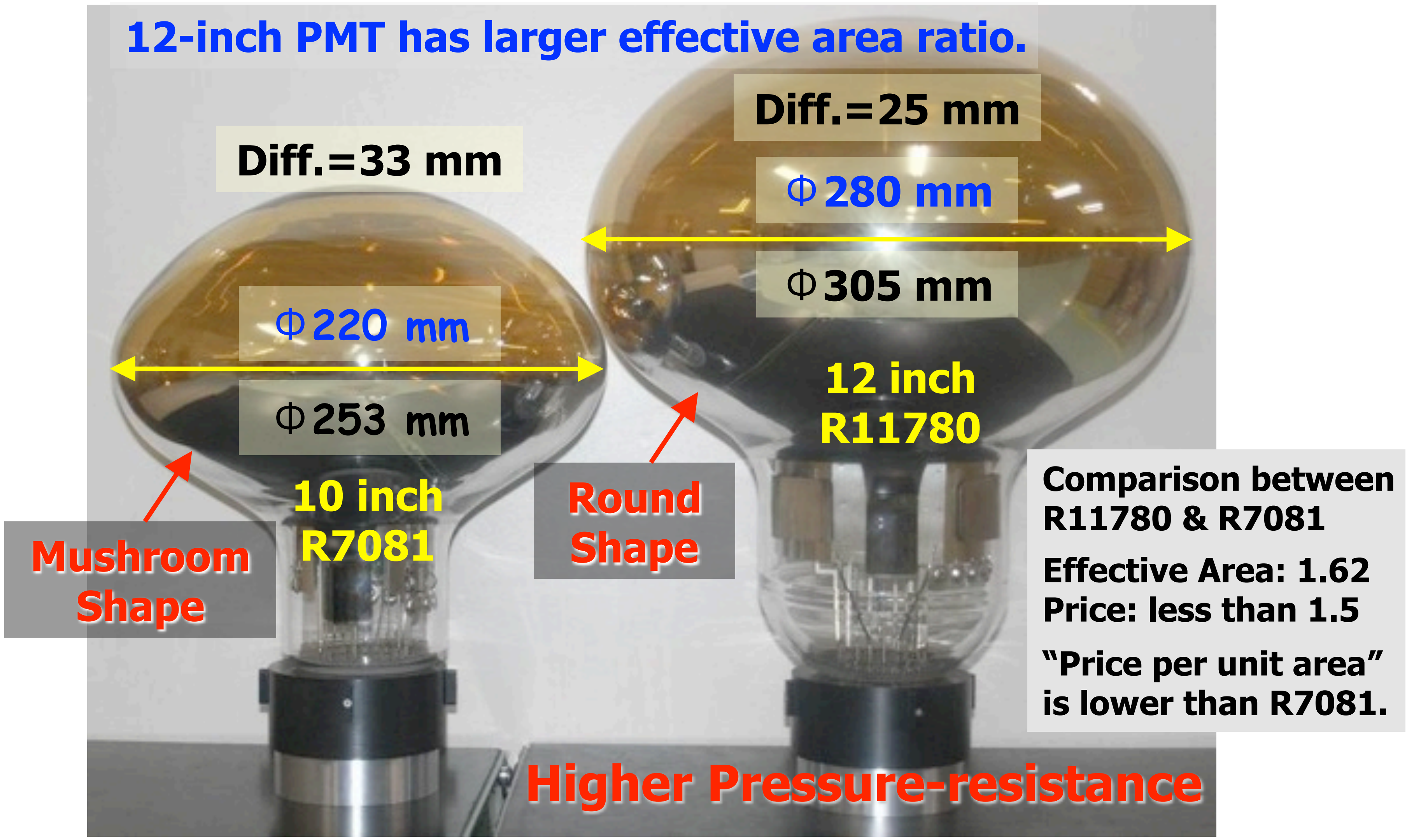
- Detection Efficiency
  - Efficiency as a function of wavelength
  - Efficiency as a function of position
- Charge
  - Width of Charge Distribution
  - Peak to Valley Ratio
  - High Charge Tail
- Time
  - Prompt Transit Time Width
  - Late pulsing

R11780 12” PMT

- Originally characterized as a PMT candidate for the LBNE Water Cherenkov Option
- Ten linearly focused dynode stages
- Available in both Standard) and High Quantum Efficiency (SQE,HQE) configurations with peak Quantum Efficiency of 21% and 32%, respectively
- Also tested “Enhanced Quantum Efficiency” Tubes with peak QE of 27%

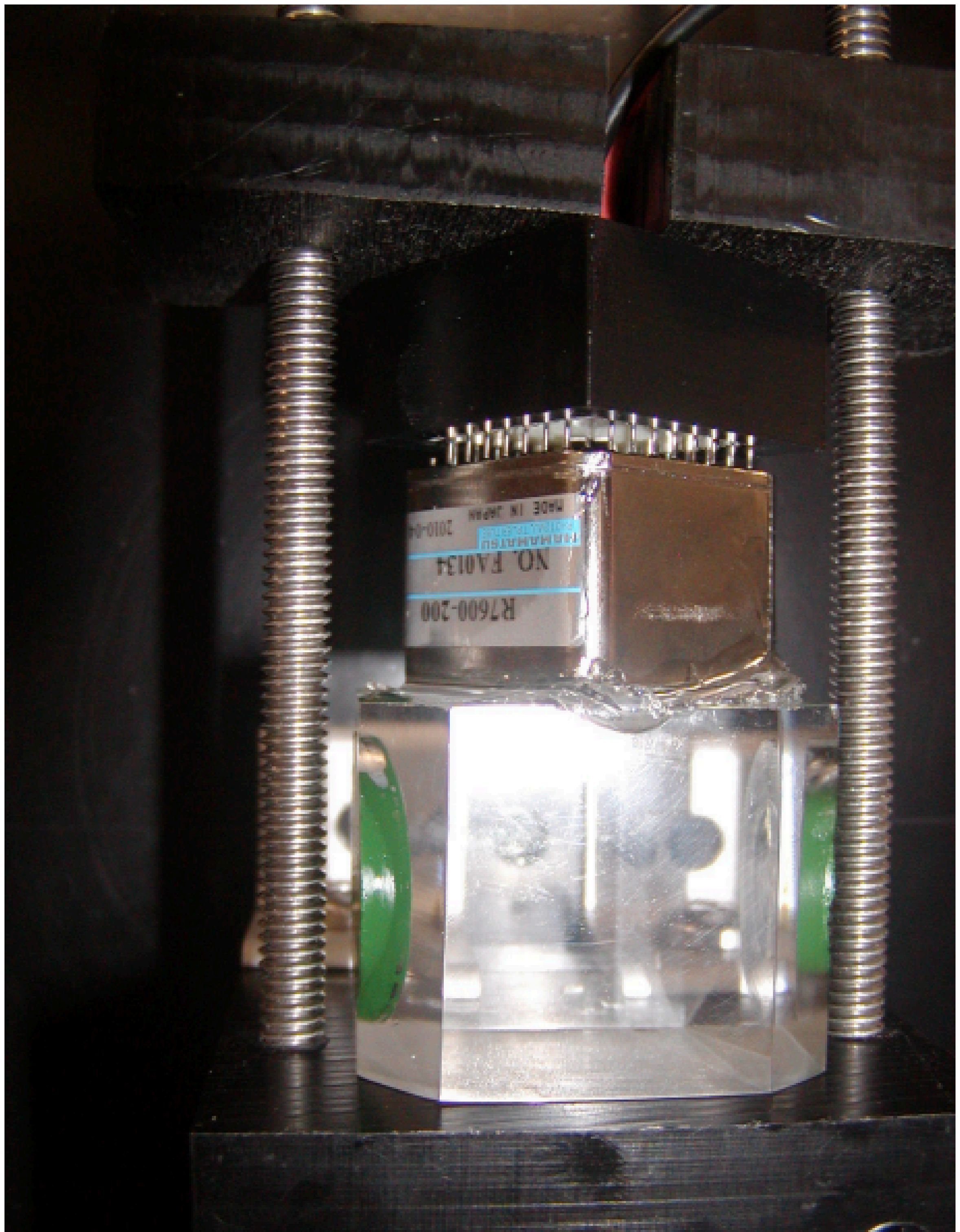


Comparison between R7081 10” and 12” R11780



- R7081 10-inch PMT well characterized and currently in use by neutrino experiments such as IceCube

Cherenkov Source



- Characterize candidate PMTs with the same wavelength spectrum as would be seen in a water Cherenkov detector

- Two 0.1 μCi strontium-90 disks

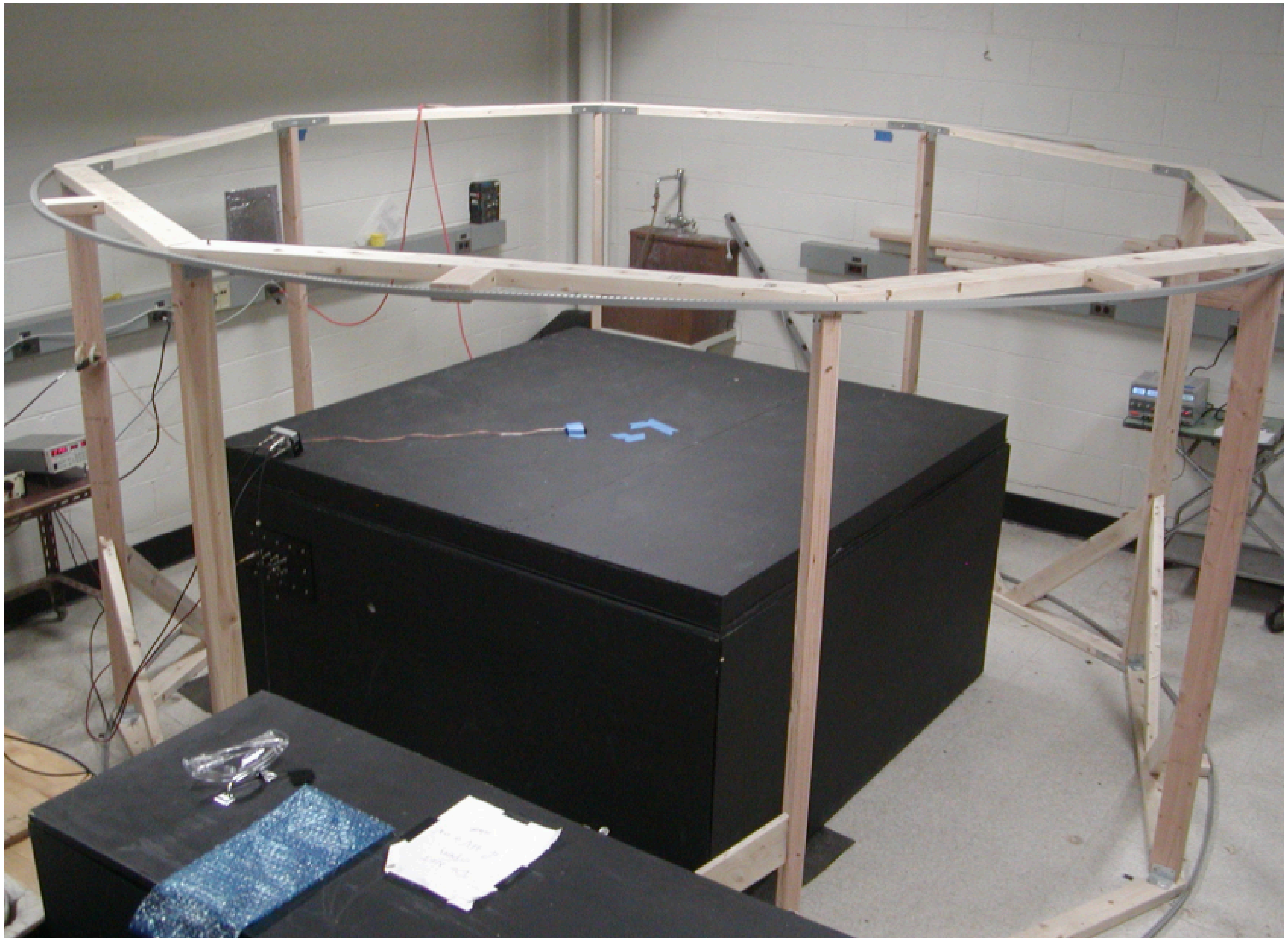
- Sources mounted on cube of UV-transmitting acrylic (from SNO experiment)

- 2” high quantum efficiency trigger PMT with <100ps jitter

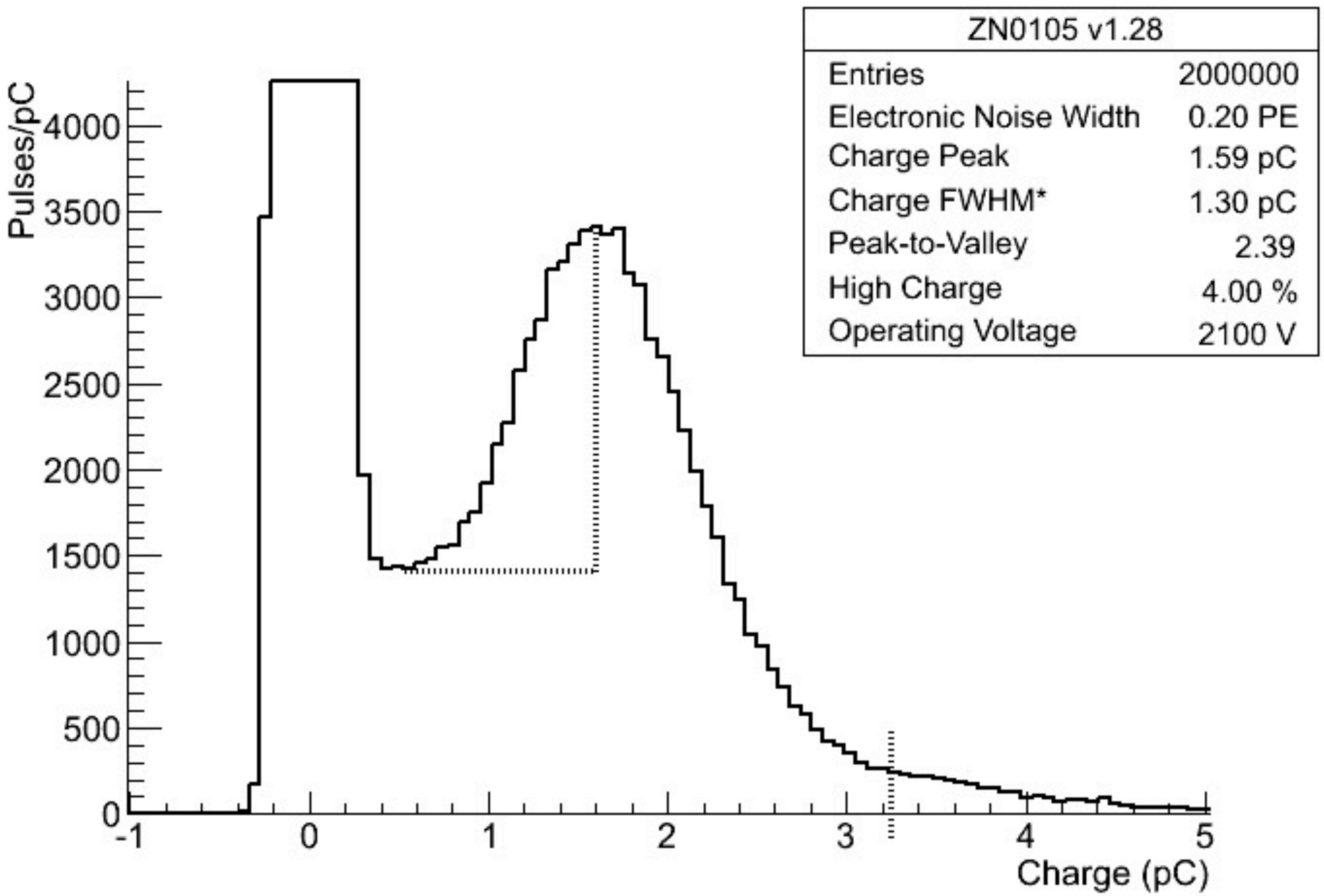
- Produces a wavelength spectrum that mimics water Cherenkov spectrum.

Dark Box Test Setup

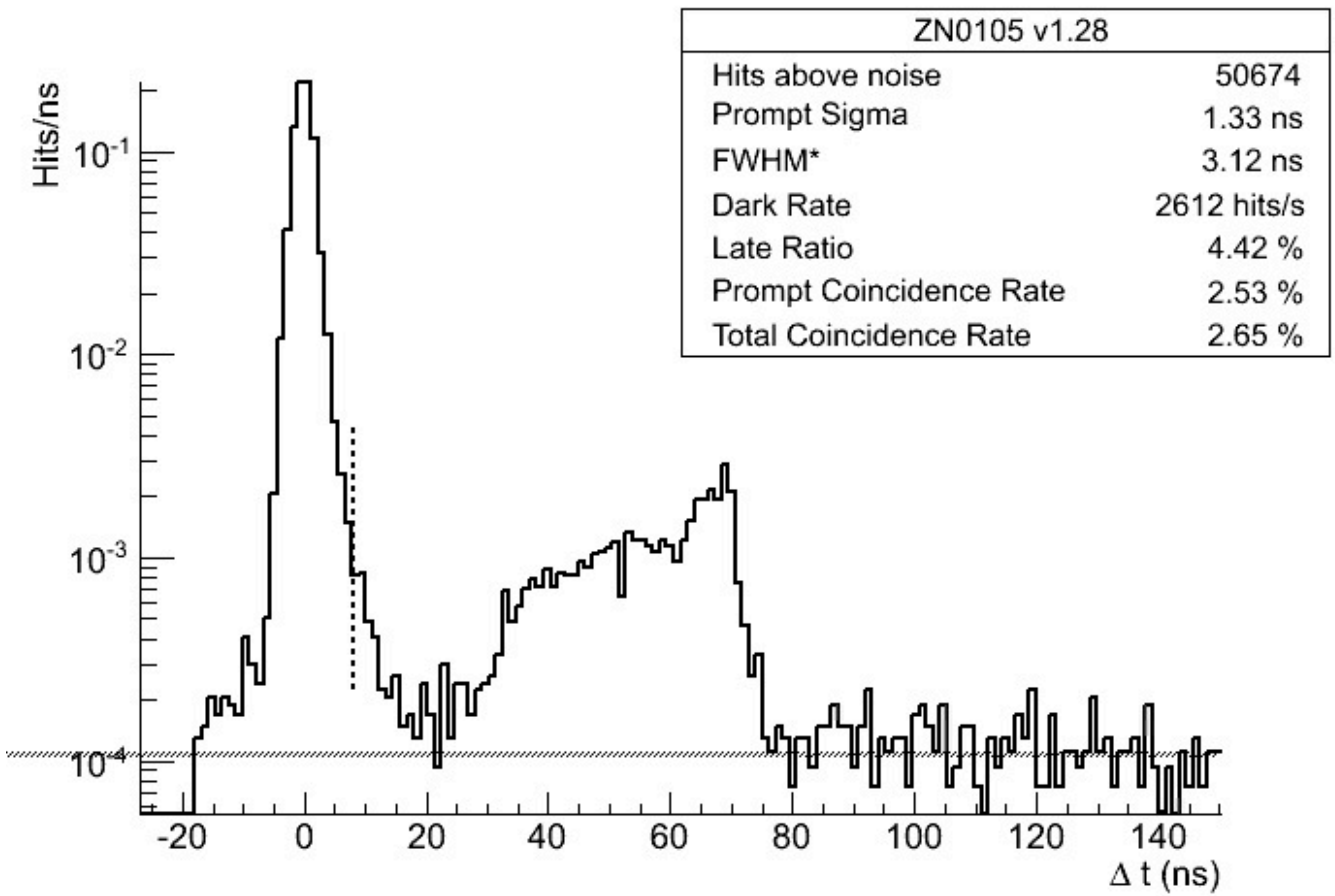
- 2m x 2m x 1m Dark Box
- Houses Cherenkov Source and Three Test PMTs
- Setup surrounded in Helmholtz coils to reduce effects of Earth's magnetic field
- *Finemet* also installed for improved magnetic shielding
- Connected to LeCroy Four channel Oscilloscope
- All Tubes tested at gain of 10^7



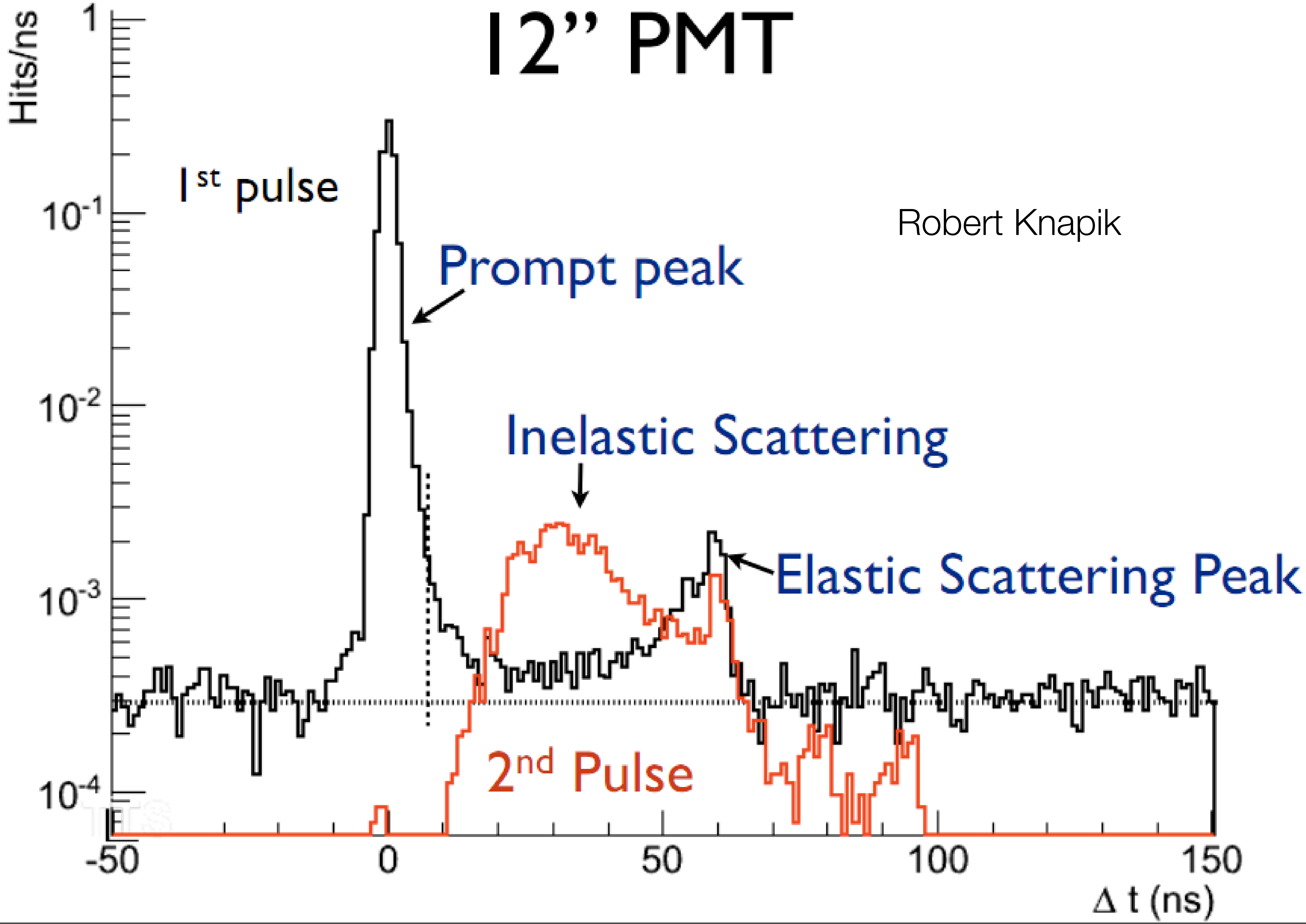
Sample Charge Distribution: 12” HQE Pmt



Sample Transit Time Distribution: 12” HQE PMT



Double Pulsing: 12" PMT



Robert Knapik

Measurements of R11780 PMT Characteristics

	Average SQE	Std Dev SQE	Average HQE	Std Dev HQE	Average EQE	Std Dev EQE	Typical 10" R11780
Charge Width	1.65	0.78	1.64	0.62	1.56	0.69	1.6
Peak/Valley	2.7	0.23	2.24	0.27	2.5	0.5	2.5
High Charge (%)	2.82	0.37	3.75	0.66	3.30	0.56	1.8
Prompt width (ns)	1.41	0.1	1.41	0.09	1.46	0.1	2.0
Late Pulsing (%)	4.42	0.37	4.2	0.294	4.03	0.5	4.0

- Charge Width Comparable between Tube Configurations
- Peak to Valley worse for HQE configuration
- Timing performance excellent for 12" compared to 10"

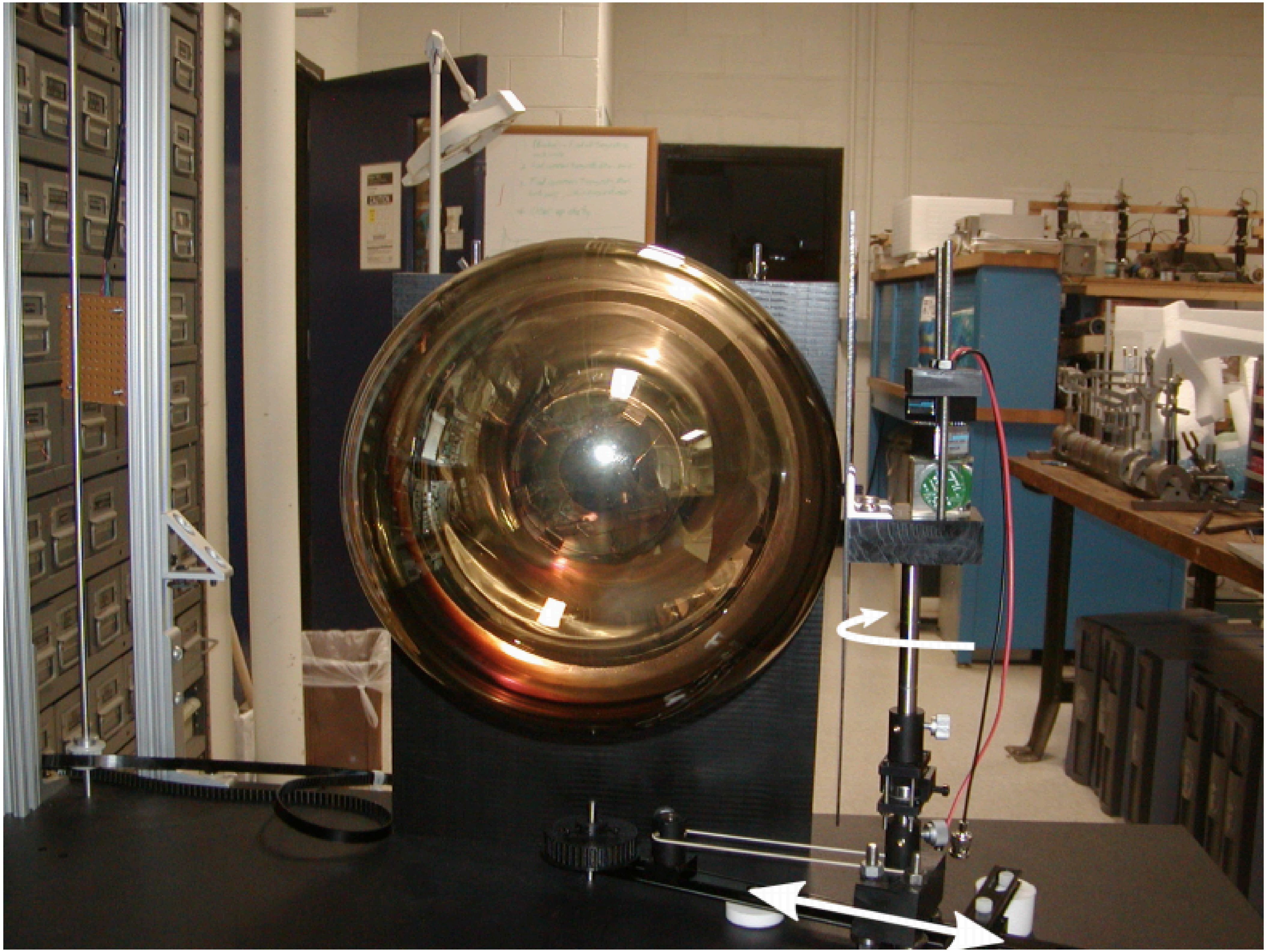
Relative Efficiencies

	Average	Std Dev
HQE vs. Std Relative Efficiency	51%	14%
HQE vs EQE Relative Efficiency	17%	16%

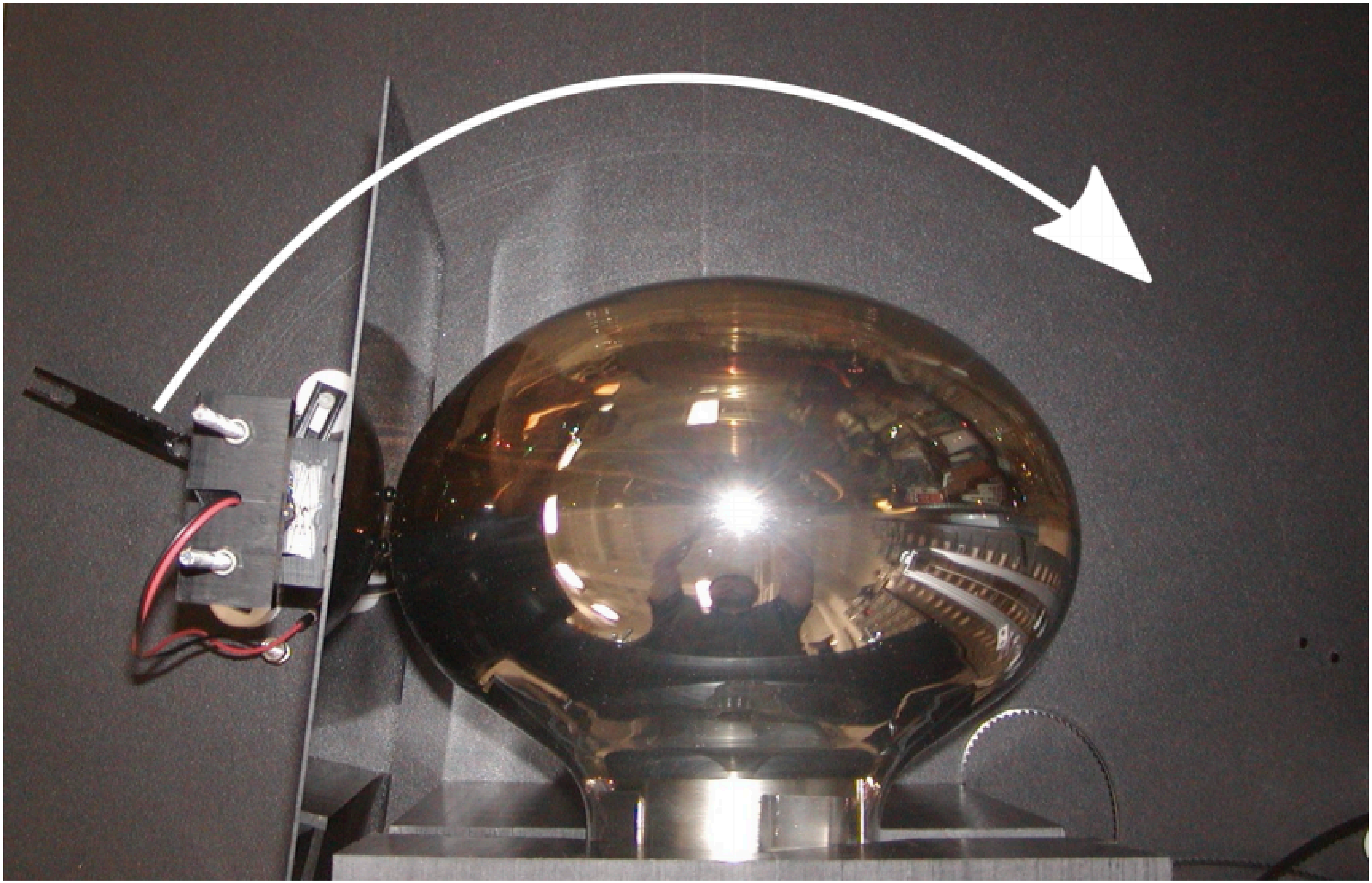
- Relative Efficiencies measured by comparing prompt coincidence rates.
- HQE R11780 is on average 50% more efficient than Standard Tubes
- Database of Measurements:

  http://notdirac.hep.upenn.edu:5985/pmt-v1-28/_design/DB-update/_list/welcome/info

Scanning Arm (Anthony LaTorre, Stan Seibert)

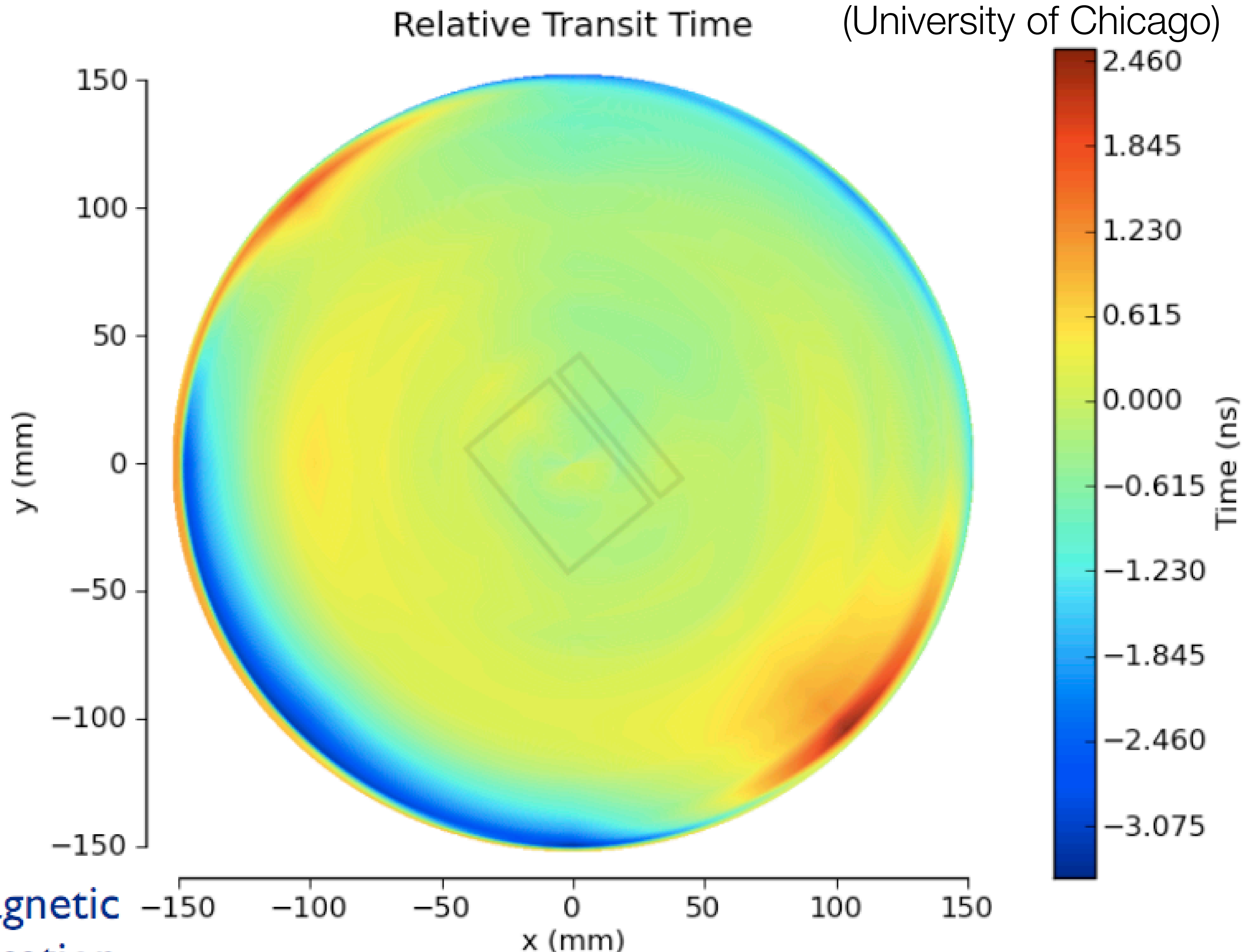


Scanning Arm



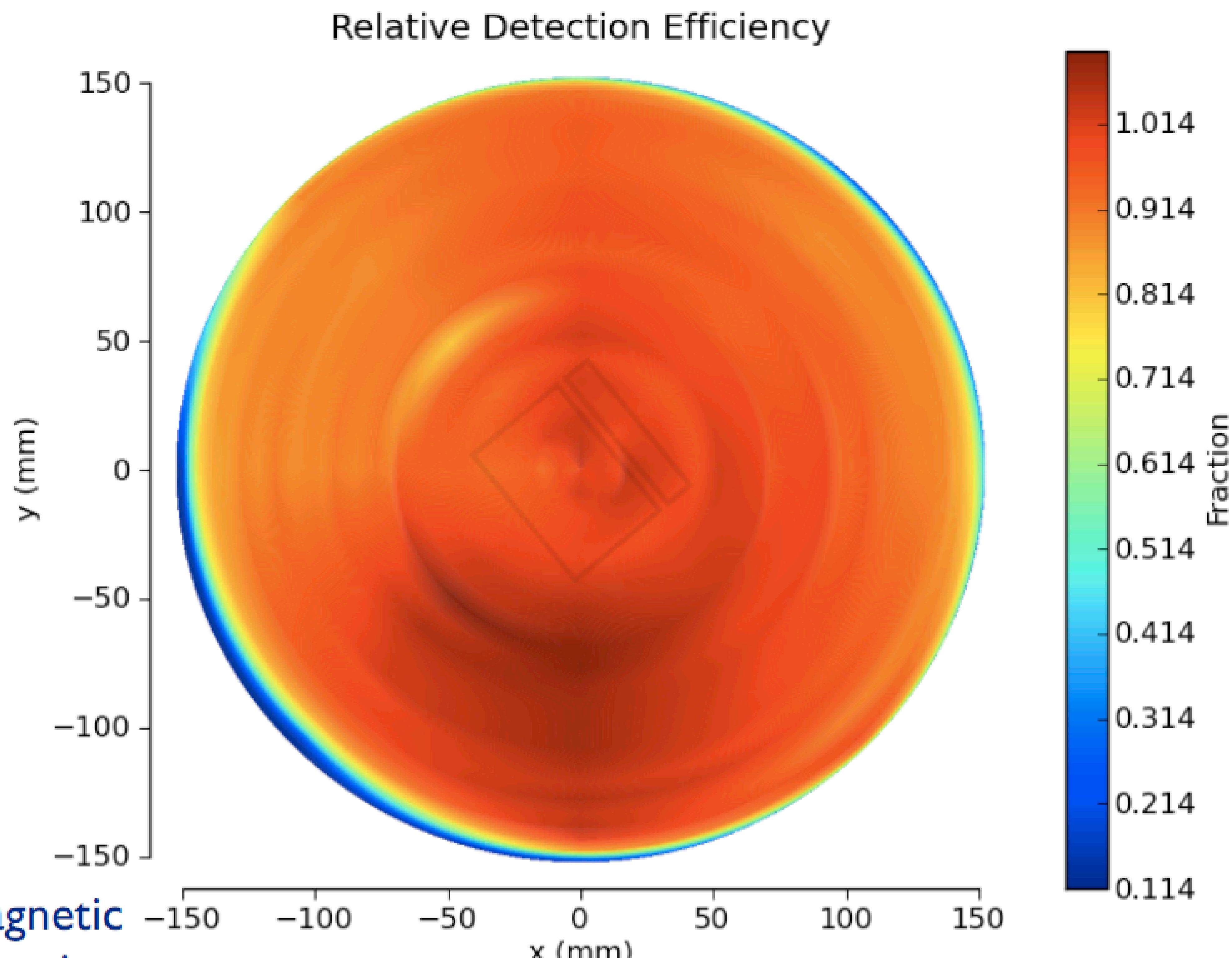
Position Dependence: 12” PMT

Anthony LaTorre
(University of Chicago)



With Magnetic Compensation

Position Dependence: 12” PMT



With Magnetic Compensation

Conclusions & Outlook

- An acrylic Cherenkov source can be used to characterize PMTs with a light spectrum close to a Water Cherenkov detector

- The 12” R11780 PMT has outstanding charge and timing performance with fairly uniform detection efficiency.

- Price per detected photoelectron cheaper than other large-area PMT models

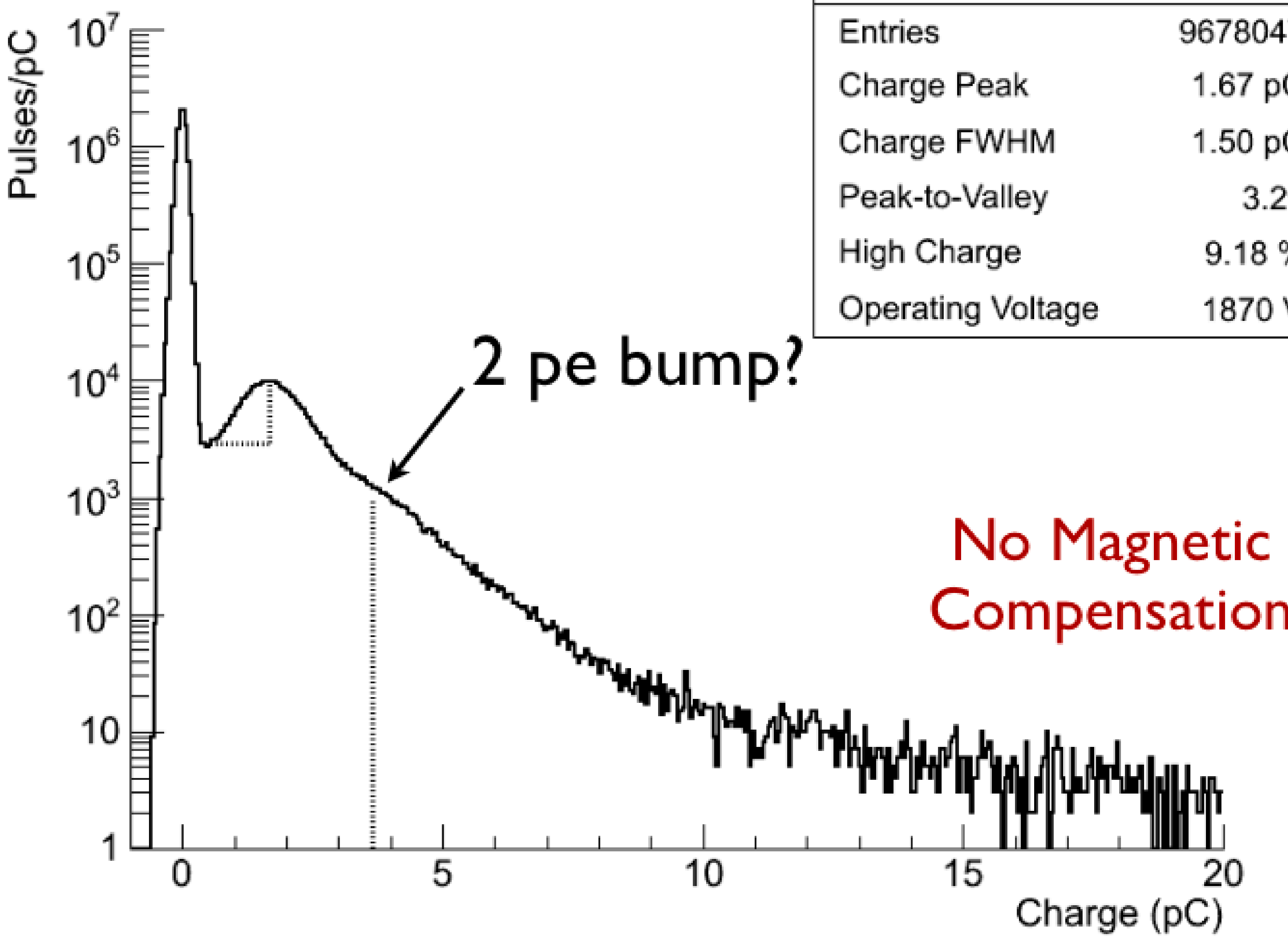
- Transit time changes by as much as 3 ns near the edge of the photocathode surface. Prototype tubes with different dynode structure under construction.

- Nuclear Instrumentation and Methods Manuscript Under Preparation

- Originally characterized for the LBNE Water Cherenkov option, but other collaborations such as LENA (Low Energy Neutrino Astronomy) have expressed interest in the R11780 PMT and the model is appropriate for any large-scale optical detector.

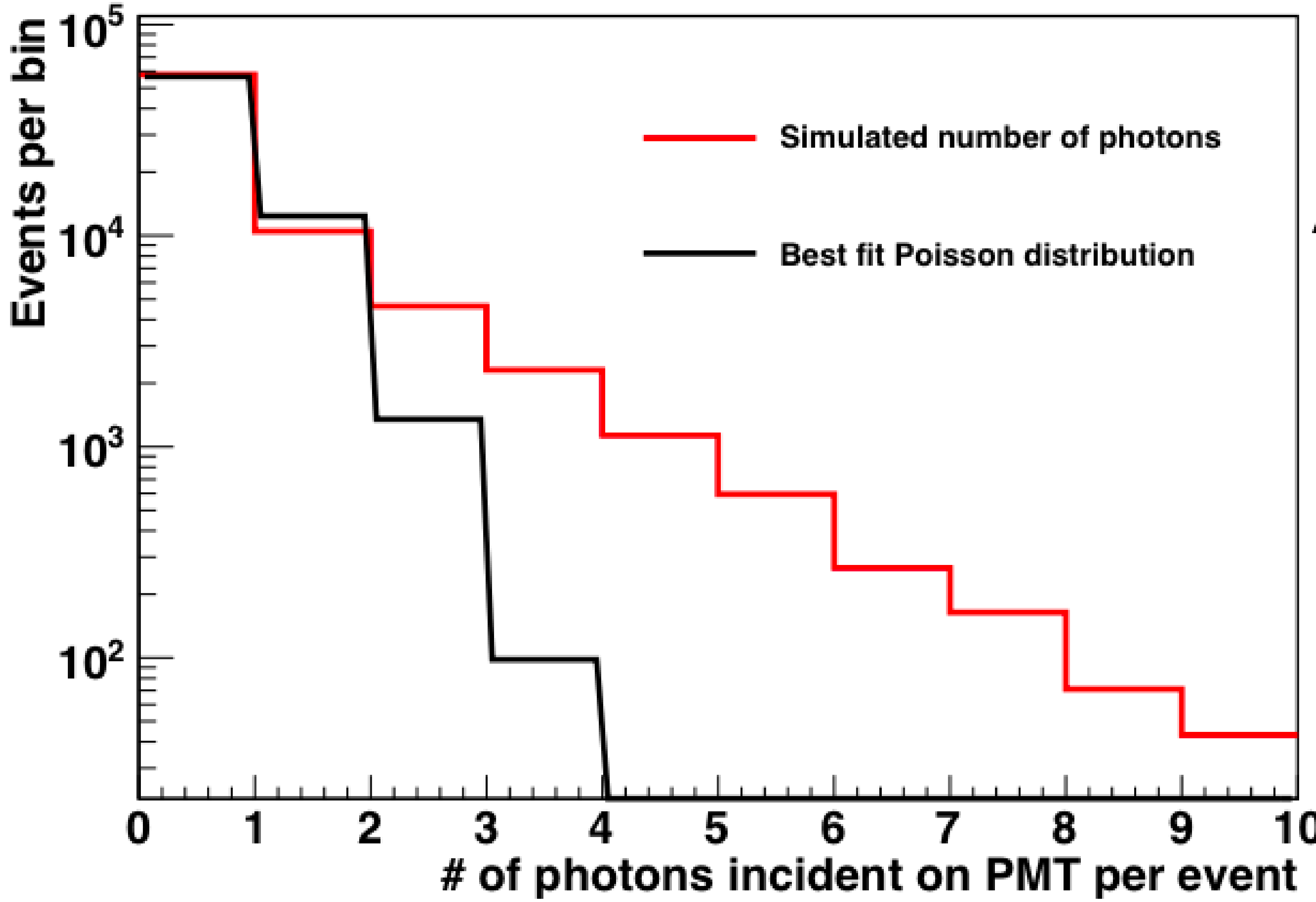
Backup Slides

High Charge Tail: 12" PMT



ZN0077 v0.20	
Entries	9678047
Charge Peak	1.67 pC
Charge FWHM	1.50 pC
Peak-to-Valley	3.29
High Charge	9.18 %
Operating Voltage	1870 V

"High Charge Tail": 12" PMT

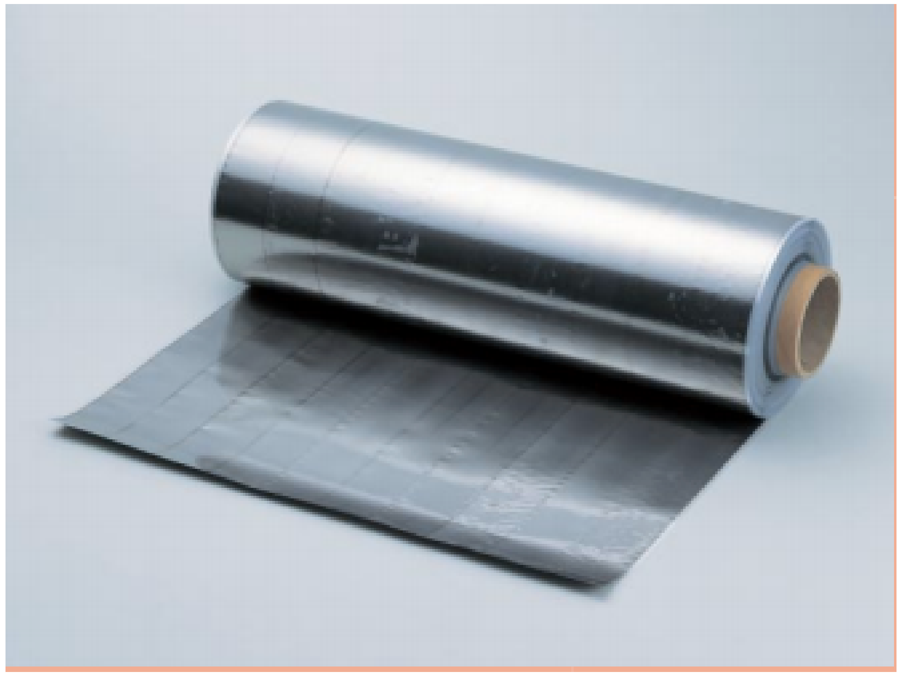


A non-poisson tail produces more multi-PE events than one would predict from the coincidence rate.

Magnetic Shielding: Finemet

- Use Helmholtz coil as a “first order” magnetic field reduction, and a magnetic shield to reduce field further.

- Light weight and flexible film version of finemet material developed by Hitachi. Maximum permeability: 70,000. Maximum flux density: 1.13T.



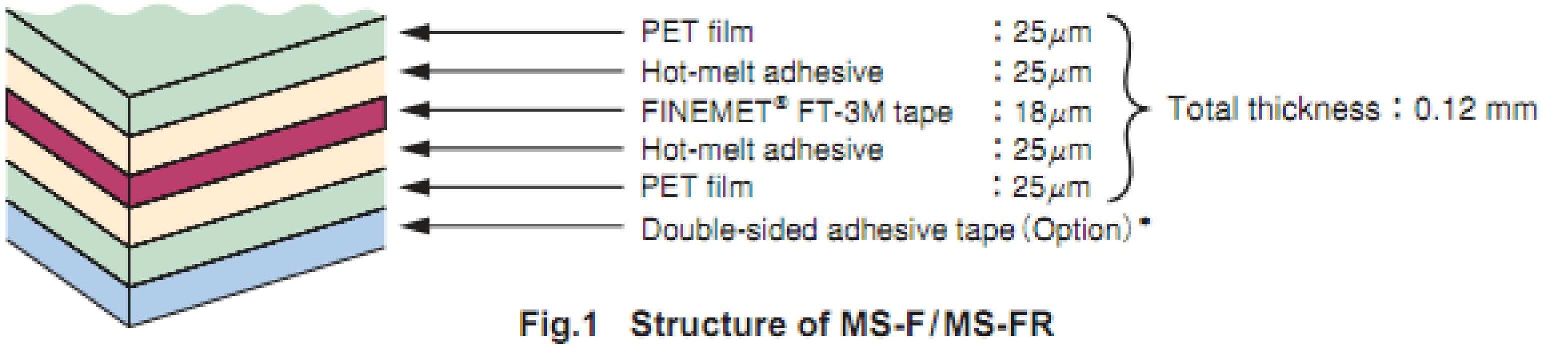


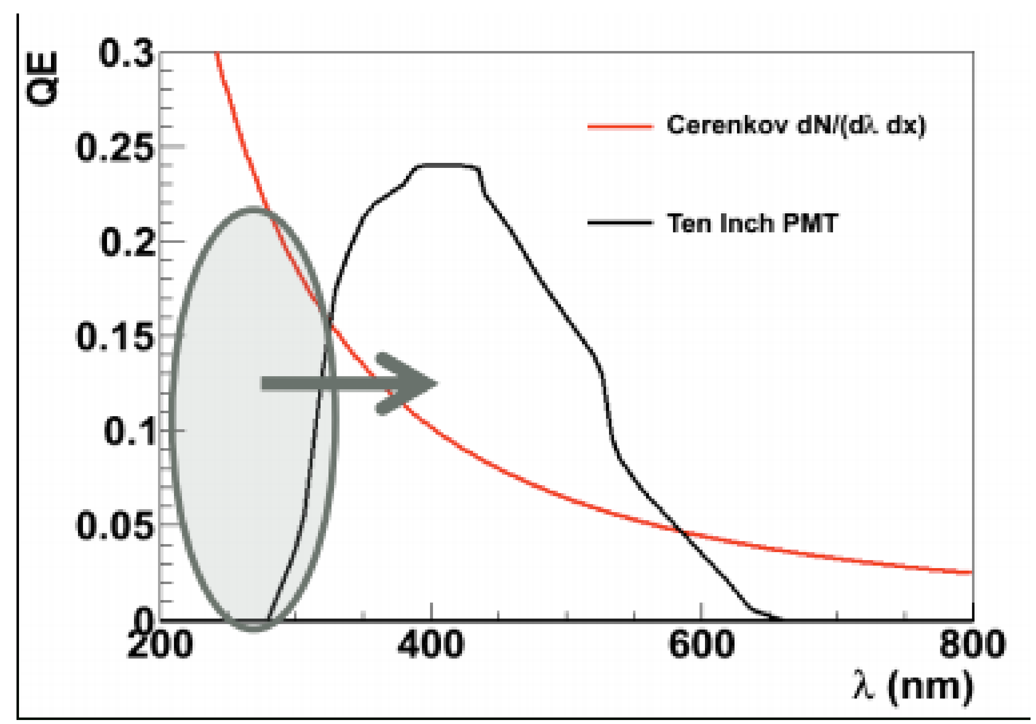
Fig.1 Structure of MS-F/MS-FR

Dark Rates

	Average SQE	Std Dev SQE	Average HQE	Std Dev HQE	Average EQE	Std Dev EQE	Typical 10” R11780
Dark Rate (Hz)	3891	631	4530	1897	5585	3600	3000

Outlook: Wavelength shifting plates and Light Collectors

- Wavelength Shifting Coating on PMT face
  - Initial Investigations by IceCube in the 90s
  - Can be combined with other light collection methods
- Wavelength Shifting Plate
  - Easy to manufacture and shape
  - Being worked on at CSU
- Reflective Winston Cone
  - Minimal wavelength dependence and no time delays

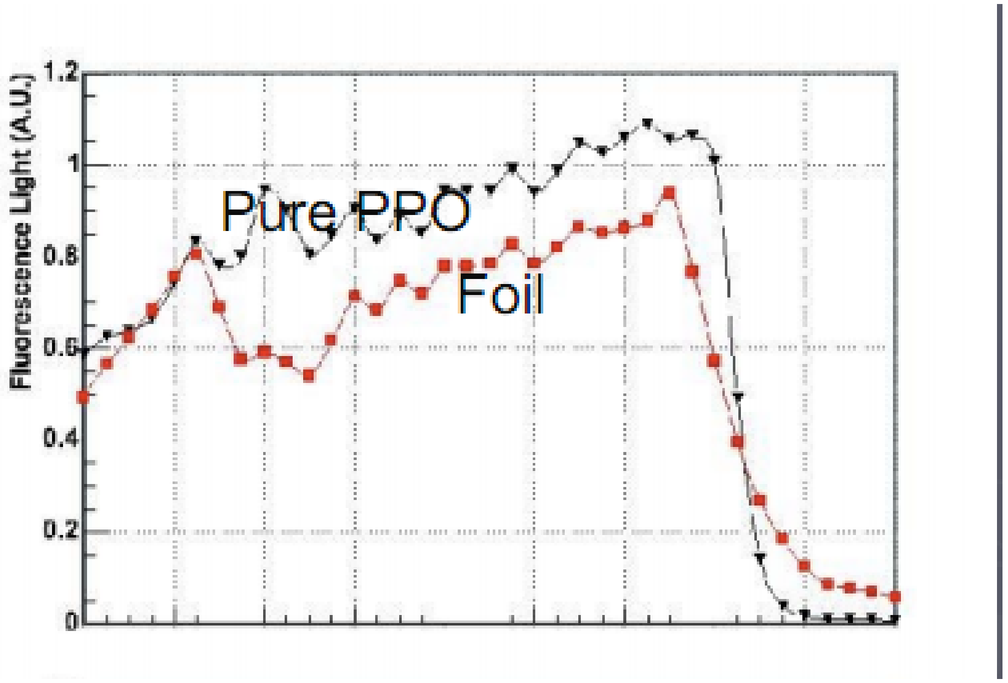


Wavelength Shifting Plastic Foil

0.5 mm thick plastic foil
PPO dissolved in plastic film called THV

~23% improved light collection in air, ~15 percent in water. Sensitive down to 200nm

Can be combined with other techniques



Winston Cones and WS Plates

- ~50% increase in light collection efficiency with WC sim

- PVT base with different fluor options.

- Increase light collection up to 25% at 400nm